Quarterly Technical Summary

Educational Technology Program

15 September 1970

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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ABSTRACT

Work this quarter has been directed primarily at component
development for LTS-2 and investigation of various instruc-
tional strategies utilizing LTS-1 and aimed at firming up
system specifications for LTS-2. A special study of the
potential application of technology to education for the handi-
capped was carried out during the quarter.

F. C. Frick
15 September 1970   Program Manager

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EDUCATIONAL TECHNOLOGY PROGRAM

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EDUCATIONAL TECHNOLOGY PROGRAM

I. LTS-1 DEVELOPMENT

Preparations for using the LTS-1 terminal for test purposes have been made during the quarter. The goal is to provide a teaching system that <u>functions</u> very much like that anticipated for LTS-2, although it is realized with very different hardware. The items that have received most emphasis are reported here. They include a statement of the general instructional strategy afforded by the machine. A redesign of console functions provides for three-digit numerical responses by the student and a smoother scheme for scanning back and forth over recent material. The program for automatic recording of student responses has been designed and is being implemented. Additional lesson materials are being prepared. All these activities are directed at two main goals: (1) to test and debug the system and (2) to discover the relative merits of different hardware and instructional techniques.

A. Instructional Strategies

An important feature of the Lincoln teaching system concept is the emphasis on and provision for some degree of student control over the instructional program. Most of the adverse reaction to programmed instruction and teaching machines can be attributed to feelings on the part of the student that the system is not responsive to him and that he is being manipulated in some simple, mechanical fashion. In fact, there are many possible entry points and routes through even highly structured material and the particular path taken should recognize and be a function of the student's individual background, ability and interests.

Most published programs of instruction, however, proceed in a linear fashion through a fixed succession of small steps or employ only very simple branching techniques. Often the only deviation from a set route through the material will be the correction of an erroneous response and the admonition to go back and try again. This lack of flexibility stems in part from the fact that a more adaptive system comes at a price in machine complexity — logical processing and/or storage required — and in the demands made upon the course author. In order to evaluate these factors and explore some of the potential trade-offs, LTS-1 has been provided with several general operators designed to give the student the capability of "browsing" or in other ways controlling the instructional sequence. A number of short courses are under development to explore the effectiveness of these operators and, in particular, to determine how difficult it is for the author to exploit their potential.

These special features are represented by the INDEX, SELECT and ? keys. INDEX implies that the author has provided index or course outline frames by means of which the student can orient himself and select particular topics for study and review. The SELECT key permits him to proceed directly to these particular blocks of material. With sufficient ingenuity the author can use "index" frames to challenge the student to jump ahead, to suggest relationships and connectedness in the material and, in particular, present an overview that will enable the student to plan his own sequence of study on the basis of his present knowledge and needs.

The author may also capitalize on the SELECT key by preparing "glossary" frames. A typical application would be to subscript technical terms or other textual points. Entering the

appropriate number and using the SELECT key would retrieve a frame or frames with definitions, auxiliary information or even additional examples or exercises. In much the same fashion the ? key can be used as an "I don't know" response to questions or, more generally, as a request for further or alternative explanation. If the author does not supply specific amplifying material, the ? key may default to a request to the instructor for help.

It should be noted that the course author may make use of these facilities or not. The student also has the option of scanning back and forward over recent frames, relying on his memory as a guide to their content. These features are summarized in terms of the functions of the student response keys in Table I.

TABLE I CONSOLE KEYBOARD FUNCTIONS	
Work Mode	
Keys	Student Action
YES, NO	Answer question
A,B,...F	Multiple choice
?	Query: "don't know"
Number + GO-ON	Enter numerical response
Scan Mode	
BACK	Move back through previous frames
RETURN	Move forward toward latest frame
INDEX	Show index frame
Number + SELECT	Go to frame of given number

B. Redesign of LTS-1 Console Program

A revision of the design of the console control program has been accomplished during this period. The prior version provided for multiple choice responses and an index-and-select function that permits browsing by the student anywhere in the lesson. These have been improved in three ways. (1) The student may progress backward over recently covered material and return in a more orderly manner than before. (2) The student may enter a numerical response of up to three digits in the numerical keyboard. Provision is made for comparing the response with several possibilities, including "no-match," resulting in different branches. (3) The program for recording student performance data on magnetic tape has been incorporated. These modifications and additions were made smoothly, proving the validity of the basic Educational Technology Operating System (ETOS) program.

C. LTS-1 Hardware Improvements

In order to minimize audio access time in LTS-1, a modification to the Recording Facility was installed. It ensures that cue signals are always recorded at the same angular position on the magnetic disk. Consequently, all audio segments start and stop at a fixed angular position.

This fix permits precise prepositioning of the magnetic pickup and minimizing of access time. A similar modification was made on the student terminal. Even though the student may escape the audio segment at a random time, the rotating pickup still halts at the correct angular position. Thus, although the audio halt may be delayed up to three seconds, it always starts promptly. Repackaging of the Student Transient Memory for use at the LTS-1 student console has been accomplished.

D. Preparation of Lesson Materials

A programmed lesson for presentation on LTS-1 is being prepared from published materials that have been used to teach Air Force personnel about solid state devices. The lesson conveys the same information, but the information is packaged in a form that is suitable for the interactive learning that LTS-1 supports. A special feature of the lesson is that it incorporates examples of learner responses which reflect complex contextual and informational dependencies — even though LTS-1 accepts only responses of the multiple-choice push-button type. Consider, in particular, a sentence that might be used to quiz a student about semiconductor devices: "Because atoms of [acceptor (1); donor (2); insulator (3)] substances introduce [electrons (1); holes (2); protons (3)] into germanium crystals, the crystals are called [E-Type (1); O-Type (2); P-Type (3)]." The student's response should consist of three numbers which identify the words that complete the sentence correctly. Since this method of testing involves recognition of the correct response, the method is less demanding of the student than the more traditional method that requires him to recall the correct response from memory. Often, however, we are not as interested in a particular verbal response as we are in the student's appreciation of relationships. The present method appears to serve that end quite well.

Another set of lesson material is being prepared to provide a formal test of the use of the spoken versus the written word. The lesson is on meat carving for training headwaiters and chefs. It is quite factual in content and will provide a kind of vocational material that contrasts with those already prepared on single-sideband modulation and solid state physics. The main experiment will test the hypothesis that the student will progress more rapidly if instructions that go with photographic illustrations are presented to the ear rather than to the eye.

E. Applications of Lincoln Training System

The principal goal of the project is to develop prototypical hardware and lesson material for military technical training. Nonetheless, an effort to assess the potential of the system for application in other areas has been made.

During the quarter we have met with several education consultants to discuss various aspects of special education in the public sector. The objective of these meetings was to obtain a better view of the problems and techniques associated with educational processes which involve tutorial situations (e.g., speech therapy, remedial reading) or which have unusual curriculum demands (e.g., education of the retarded). These areas are of interest because they are an order of magnitude more costly than conventional public education, and there is a shortage of professionals who are experienced in them. For these reasons, it is believed that they might benefit from a computer-assisted instructional technique of the type we are developing. The consultants were unanimously of the opinion that the Lincoln system would indeed be of value in a wide variety of areas of special education.

II. LTS-2 DEVELOPMENT

During this quarter our efforts were directed toward the development and evaluation of components for the prototype microfiche system. Each microfiche will contain 192 visual frames with associated binary-coded branching logic in a 12 × 16 array on one-half of the fiche, plus 192 audio frames, each of which is associated with a corresponding visual frame on the other half. Registration and frame-identification marks will also be recorded on the microfiche to aid in frame location. The microfiche format is illustrated in Fig. 1. A two-axis servo-controlled film transport has been designed and is presently being fabricated. This random access film platen, along with projection optics, will be ready for testing by October. Several prototype
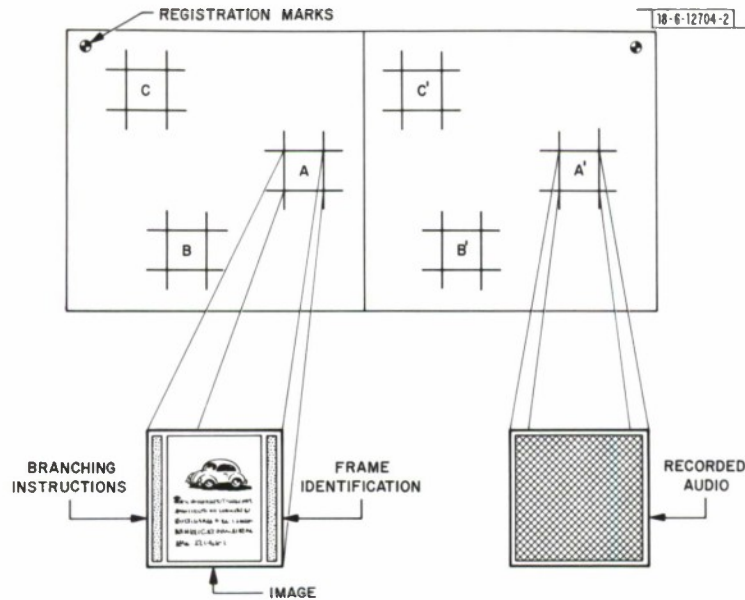

Fig. 1. Microfiche format for random access in LTS-2.

micro-image cards (148 × 210 mm) are being produced for use with the film platen, and the precision of frame positioning, will be measured. A tentative design for the audio record/read system has been developed, and components are presently being fabricated. Specifications for the self-contained logical processor have been developed, and design of this subsystem has begun. Samples of visual/audio microfiche are being produced for system test and evaluation.

A. Random Access Film Transport and Projection System

The mechanical design for a prototype random access microfiche system has been completed and fabrication is now in progress. The fiche transport mechanism is a precision x-y table with a closed-loop servo drive. Position control will be accomplished by using 8-bit digital inputs, 4 on one axis and 4 on the other. Logic will be provided to convert these inputs into switching signals which will control the position of the table via FET switches working from a ladder network. The ladder network is necessary to provide voltage signals for describing each row, or column, of images. This derives from the fact that the state of the art does not provide reasonable feedback sensors with sufficient linearity or precision to describe the desired positions with the required tolerance. It therefore requires that the table be "tuned" to each individual row

or column and depends upon stable and repeatable circuitry to provide the desired locations on the fiche.

A breadboard of the servo drive (less the table) has been built and operated. Redesign of the amplifiers and associated components is under way, based on the results of testing the performance of the breadboard system.

B. Audio Record/Read System

An audio frame is 8.1 × 8.1 mm. Storage of one minute of speech in this frame, assuming a 10-kHz sampling rate, requires an area per sample on the film of 10 × 10 μm. One way to do this is to record each sample directly on the film and then read it out sample by sample as shown in Fig. 2. A 5 × 5-μm spot should be used to access the samples so as to avoid crosstalk between adjoining elements. The use of such a narrow beam of light implies precision optics, tight mechanical tolerances and highly accurate scanning. In addition, because of the small data-sample area, scratches, pieces of dust, or film imperfections can easily obliterate parts of the data. Another way to record the data is by the use of diffraction gratings. Each sample, instead of being recorded in a 10 × 10-μm area, is recorded as a diffraction grating over a 150 × 150-μm area as shown in Fig. 3. In order to preserve the same information density, at least 225 diffraction gratings must be superimposed. To be able to discriminate between the samples, each grating must have a different spatial frequency. When the

Fig. 2. Optical recording and readout of data by direct method.

150 × 150-μm patch is illuminated by a light beam, light is diffracted by each grating in a direction related to its spatial frequency, thus allowing the samples to be detected by an array of photodetectors. By recording the data over a larger area, a certain amount of redundancy is
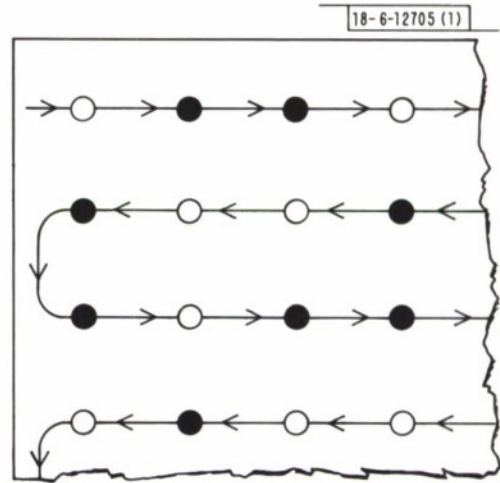

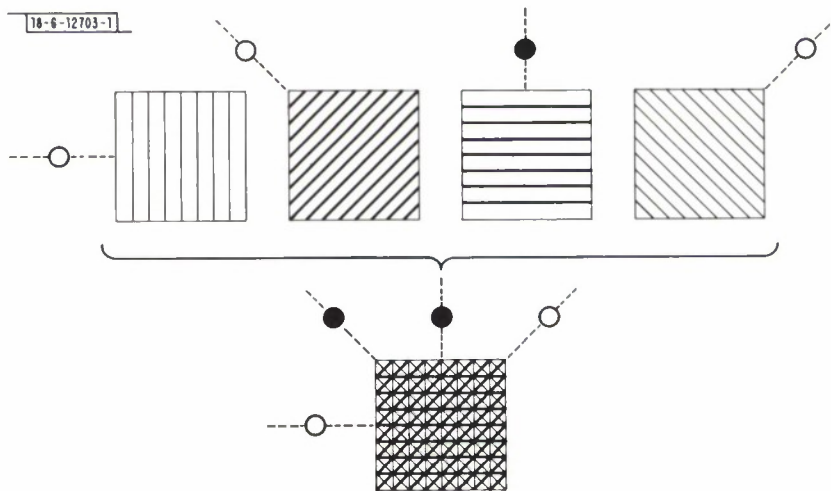Fig. 3. Optical recording and readout of data by diffraction-pattern method.

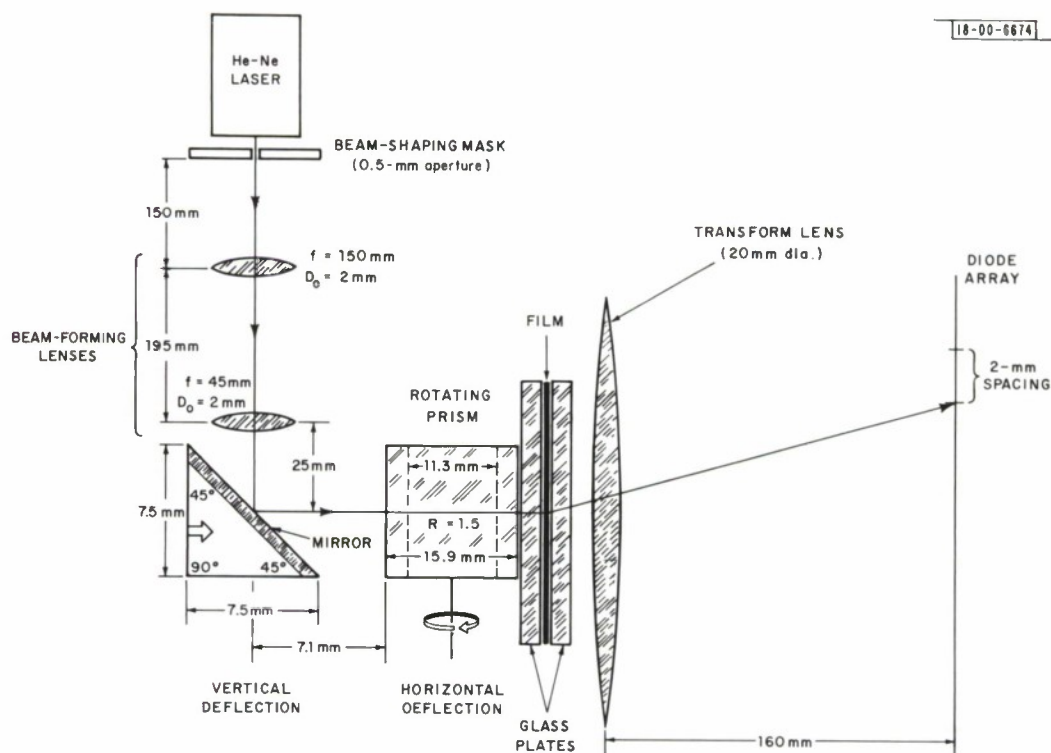|	TABLE II	
COMPARISON OF READOUT SYSTEMS FOR DIRECT AND DIFFRACTION RECORDING		
Design Feature \ Recording Technique	Direct	Diffraction
Beam size (μm)	5	150
Mechanical talerances (μm)		
In plane af fiche	±1	±30
Perpendicular to fiche	±10	±8000
Optics	Law f/na. lenses	Moderate f/na. lenses
Scanning linearity	±0.025%	±0.5%
Imperfectian sensitivity	High	Law

Fig. 4. Optical system far audio readaut from diffractian-pattern record.

obtained for protection against dust, scratches and imperfections. In addition, the 150 × 150-μm light-beam size results in simpler optics, relaxed tolerances and less stringent scanning requirements. Table II compares the readout requirements for the two recording techniques.

The recording system now under investigation uses two-dimensional diffraction gratings for storage of the sampled audio signal. Each audio sample is stored as a two-dimensional sine wave, with peak amplitude transmission proportional to the square root of sample magnitude. One of two spatial frequencies is used for each sample, depending on sign. The sine wave is recorded in a 150 × 150-μm area, and 256 of 512 possible spatial frequencies are superimposed in this "diffraction patch," representing sign and magnitude of 256 contiguous audio samples. A block diagram of the optics for the audio read system is shown in Fig. 4. The system uses a He-Ne laser source, beam-shaping optics (to produce a 150-μm-diameter beam), a beam-deflection system for scanning the 8.1 × 8.1-mm audio record, an output lens which forms the Fourier transform of the illuminated patch on the photosensor array, and two 10 × 10 arrays of phototransistors for sensing the data pattern. The laser currently being used is a continuous-duty He-Ne gas laser, producing 4-mW output power. The laser beam diameter is 1.6 mm, and the full-angle beam divergence is 0.7 mrad. A mask is first used to form a controlled spatial distribution of the laser beam, and two lenses (used as an inverse microscope) reduce the beam size by a factor f_2/f_1, while retaining the beam shape. The focal length of the second lens is chosen to permit insertion of the beam-deflection system between this lens and the film. Measurements are now in progress to determine optimum values for f_2, f_1, and the mask dimensions, in order to minimize system crosstalk.

The laser beam-deflection system shown as part of Fig. 4 uses a linear mirror scan for vertical deflection, and a rotating transparent prism for the horizontal scan. The linear mirror moves the laser beam vertically a distance of 7.5 mm, in approximately 60 seconds, while the prism deflects the beam 7.5 mm horizontally in approximately one second. The horizontal deflection produced by the prism is a nonlinear function of prism rotation angle, but has the advantage of inherent flyback. Two techniques to compensate for scan nonlinearity, one optical and the other mechanical, are being studied. Drive mechanisms for the scanner are currently being constructed. Prism rotation and the mirror scan produce optical pathlength changes, but preliminary calculations show these changes to have negligible effect on the beam shape, and measurements are being made to confirm this.

Another optical beam-scanning technique has been investigated, and consists of a mirror mounted on a precision galvanometer movement followed by a lens (for angle-to-distance conversion), shown schematically in Fig. 5. At a focal distance of 125 mm, a 15-mm linear scan was achieved with linearity good to within 10-μm RMS, and long-term drifts of ±15 μm.

A transform lens is used to focus on the phototransistor array the light diffracted by the hologram. Each phototransistor is located so that light diffracted by a given spatial frequency in the hologram is focused on it. For a phototransistor spacing of 2-mm center to center, the lens required is a modest f/8 with a focal length of 160 mm.

The output detector is an array of phototransistors which are spaced at approximately 2 mm with useful areas of about 1 × 1 mm. In order to ensure an output range of 40 dB (to retain speech quality), each detector must provide detectable current for a minimum of about 1-nW input power. In the audio-on-fiche approach currently being investigated, low incident light per detector must be overcome by local current gain in either the photodetector or nearby on the same silicon chip. The most straightforward solution appears to lie with high-sensitivity (large collector area)

LIGHT
BEAM

`18-00-6675`

GALVANOMETER

V_{IN}

MIRROR

θ

θ

θ ANGLE

d

LENS

f

Fig. 5. Beam scanner.

COMPUTER-GENERATED MASK

LASER-ILLUMINATED IMAGE
(λ = 633 nm)

`- 6-12706-1`

0.0005 in.

0.0075 in.

0.015 in.

15 × 15 M-SEQUENCE
REPEATED 2 × 2

15 mm

15 mm

IMAGE IS 300 mm BEHIND MASK
ELEMENT SPACING IS 1 mm × 1 mm
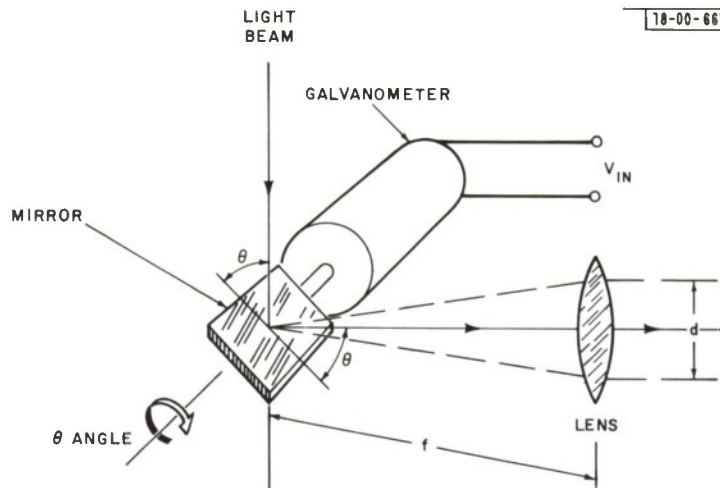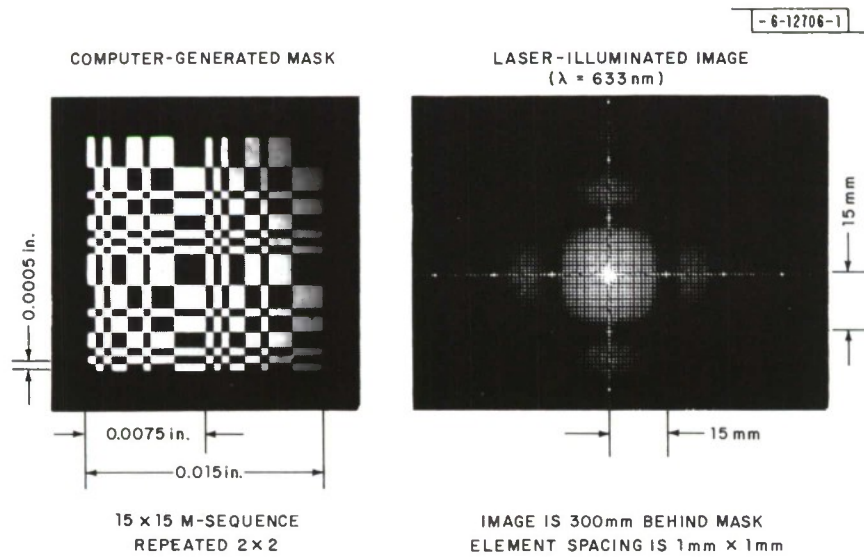
Fig. 6(a-b). Optical Fourier transformation with mask made by precision artwork generator.

8

COMPUTER-GENERATED MASK   LASER-ILLUMINATED IMAGE
                                        (λ = 633 nm)

1.5 mm

1.5 mm

5 SINE WAVES   NUMBERS INDICATE
QUANTIZED AREA MODULATION   RELATIVE AMPLITUDES

ZERO SPATIAL FREQUENCY (DC)
25
1
10 CYCLES/mm
16
100

100   10 CYCLES/mm
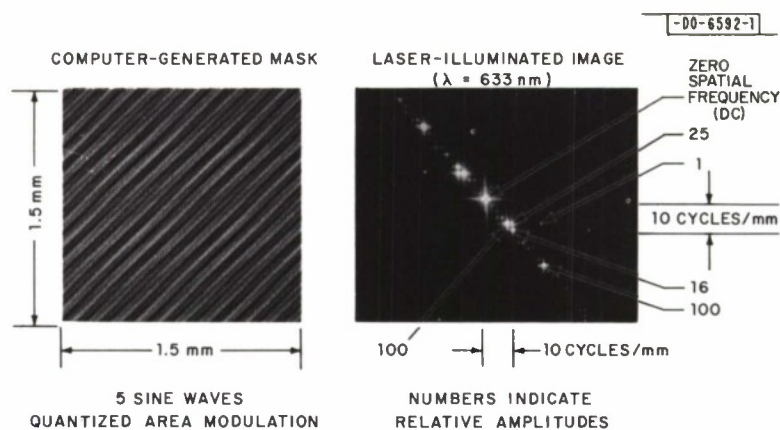
Fig. 7(a-b). Optical Fourier transformation with mask from computer-output microfilm.

phototransistors having sensitivities of ~1 mA/(mW/cm^2) at 632.8 nm. Several devices are currently being evaluated. Further efforts toward defining dynamic range, the effect of dark current on audio S/N, the feasibility of MSI arrays with local strobe electronics, and packaging are continuing.

A number of techniques are now being studied for producing holograms (diffraction patterns). Our initial effort is concentrated in the production of the 150 × 150-μm "diffraction patch." We produce a two-transmission-level sampled pattern, using computer output microfilm (COM), and photoreduce to the required size. A diffraction patch consisting of a two-dimensional maximal length shift register sequence is shown in Fig. 6(a). The pattern shown in Fig. 6(b) is the Fourier transform of this grating, and was obtained by illuminating the diffraction patch with collimated, coherent light. A diffraction patch consisting of five superimposed spatial sine waves, of different transmission amplitudes, is shown in Fig. 7(a) and its transform is shown in Fig. 7(b).

Several other laboratories are, or have been, engaged in the development of film-based read-only memories using holographic techniques.[*][†] Some of these projects are for lesser, some for greater, information-storage densities than planned for LTS-2. These activities are being surveyed for technology applicable to the development of the complete LTS-2 system, including the generation of lesson materials.

C. Related Component Research

A PIN-SC/25 PIN diode x-y position sensor was tested for possible use in vernier position control of the film platen. The diode's 19-mm^2 active region has quadratic leads bonded to the n-material. When properly biased, an incident normal light beam produces differential currents, proportional to x-y offsets from center. Gain was set to produce approximately 0.4 V/mm in either axis, using a He-Ne laser (632.8 nm), operating at 50-μW output power. Linearity over the surface of the sensor was within approximately 2 percent for either axis; however, an accuracy of 25 μm was achieved in a nulling application, which is within the LTS-2 film positioning requirement.

[*] J. L. Reynolds, T. Y. Tao and R. S. Schools, "An Experiment Optical Memory System," NEREM Record (November 1968), p. 78.

[†] L. K. Anderson, "High Capacity Holographic Optical Memory," Microwaves 9, No. 3, 62 (March 1970).
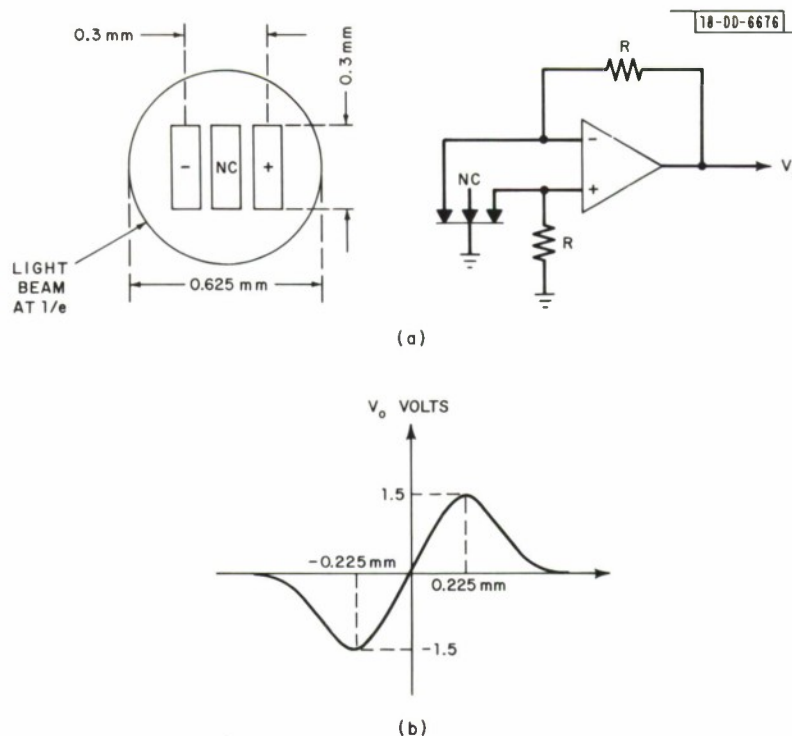
Fig. 8(a-b). Diode position sensor and transfer function.

A linear array of 0.1×0.3 mm photodiodes mounted on 0.15-mm centers, fabricated at the Laboratory by the Microelectronics Group, was tested for sensitivity, and in a position sensor application. The measured sensitivity of an individual diode was 0.25 A/W, for uniform illumination, at 632.8 nm. Two diodes were connected differentially, as shown in Fig. 8(a), and the array was scanned with an 0.625-mm-diameter laser beam, to produce the error curve shown in Fig. 8(b). The null position was repeatable to within 2 μm, which far exceeds the film-positioning requirement.

D. Self-Contained Logical Processor

Specifications for the LTS-2 self-contained logical processor have been developed, and the design of this subsystem has begun. System control is effected using student keyboard responses and photographically stored program branching logic, tentatively set at 64 bits per frame. Program branching flexibility is essentially the same as that implemented in LTS-1. The student keyboard will have additional control keys added, such as: a decimal point, sign keys, and a scan option. Details of the processor design will be discussed in the next quarterly technical summary.

E. Microfiche Test Film

During this quarter we contacted several vendors to develop a capability for producing precision microfiche, for use with LTS-2. One sample microfiche card has been obtained, and measured for frame-positioning precision. The film used was 0.18-mm mylar base with resolution in excess of 1000 white-black line pairs per millimeter. The maximum error was along the 19-element[*] row (142.5 mm) and was 31 μm. Although this is only our first sample, we are

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[*] This sample was made to an earlier format consisting of 247 frames in a 13 × 19 array, with 72 bits of branching logic.

encouraged, since we are allowing as much as ±0.1-percent tolerance. Several new microfiche cards, containing 192 sample video frames and matching the LTS-2 format, will be available for testing in the near future. Each video frame will contain textual material, binary branching logic (64 bits), a center target, and frame identification. A schematic view of this card is shown in Fig. 1, and a detailed sketch of a sample frame is shown in Fig. 9. These cards will be used to test the first LTS-2 two-axis film platen for positioning accuracy, and quality of the projection optics.

Problems related to production of a complete course card containing up to 192 video/audio frames, from a course author's material are now being investigated.

-DO-6677

TYPESETTING BY HOT METAL, TO REPRO PROOFS, THEN TO FILM

Our photomechanical unit is a custom built overhead rail Precision Systems camera, twenty-one feet long. Its Ten-Ton weight is *air suspended* to isolate the camera from any possible vibrations. The copyboard accommodates 50″ x 50″ cut and peel artwork under vacuum and has capabilities of locking up glass plates up to 50″ x 50″ square. Micrometer adjustments make it possible to line up to a tenth of a thousand in the proper plane. The back of the unit will handle film sizes up to 16″ x 20″. Vacuum glass plate holders are available to take

all standard glass plate sizes from 2″ x 2″ to 16″ x 20″ size holding glass plate in perfect plane with the copy. A wide assortment of lenses, including high resolution lenses, gives us full range capability. Each lens is collomated to its peak of efficiency. Lenses are as follows: Goertz "Red Dot" Low Distortion Artars: 610 mm – 1:1 to 5:1; 355 mm – 5:1 to 10:1; 210 mm – 10:1 to 20:1; High Resolution "Wray" Lenses: 45 mm – 50:1 to 100:1; 75 mm – 25:1 to 50:1;

125 mm – 10:1 to 20:1. Once established, a permanent V-Block is locked on our overhead rail and fixed into position. The parallel condition between the transit lensboard and copyboard with relation to the stationary rear case will maintain ± 30 seconds at any position on the

| | A | B | C | D | E | F | Fp | Ep | Dp | Cp | Bp | Ap |
| No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 | No. 9 |
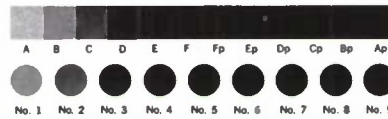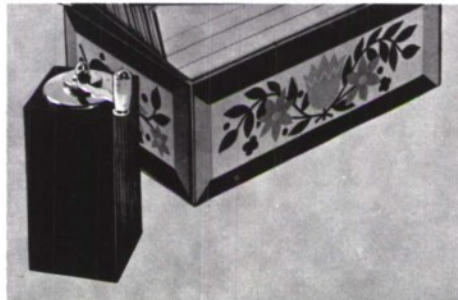
1–1   1–13

TYPE SET ON PHOTOGRAPHIC MACHINE — DIRECTLY ON FILM

The precision capabilities of our equipment are excellent for single reductions from master to final film or plate as in P/C and multilayer boards or in final reduction from step and repeat patterns. Camera speed, autopositive materials, or reversal techniques permit working negative-to-negative or negative-to-positive without additional steps.

The high degree of accuracy in the plotter mechanism and the much higher degree of repeatability on consecutive plates permit work such as multilayer boards and thin film masks to be reduced and stepped and repeated in a single process. The single process greatly reduces the time required from master to finished multiple image plate, greater line definition is obtained, and greater control over critical line weights is possible.

The maximum accuracy in image size and locationing is obtained by stepping and repeating at several times final size and then reducing to the final array size such as in the more critical thin film and semiconductor fabrication processes.

Our custom lens systems makes this procedure practical with resolution and distortion freedom comparable only to results previously obtainable with microscope optics. The intermediate multiple image plate may be corrected, lines repaired, and then used as a master from which unlimited numbers of final array plates may be made.

Multiple arrays with from 100 to 2500 images are precisely and rapidly produced using either of these two techniques. The techniques employed will be determined by the degree of accuracy in image locationing in the final plate. A reduction is made from the master and a horizontal image array

is produced. This plate is then reversed to negative form and repositioned at the object plane. This group is then reproduced at same size, or to final size, and the vertical image pattern grouping is produced.

Modern, custom-built electronic equipment available to handle artwork or film to be digitized at original of 50″x50″ or smaller. The scaling reductions are calculated by computer readout and memory systems to the desired size.

Finished film or glass masters are also digitized at one to one. Image is viewed by operator through projection screen microscope twenty times original size. All X/Y movements are made on a coordinatograph plotter within an accuracy to .0001″.

We are equipped to produce tapes with codes such as EIA, ASCII, etc. New programs can be made up upon request.

Complex drawings are digitized and the output

Fig. 9. Sample video frame LTS-2 (see footnote on p. 10).

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13. ABSTRACT

Work this quarter has been directed primarily at component development for LTS-2 and investigation of various instructional strategies utilizing LTS-1 and aimed at firming up system specifications for LTS-2. A special study of the potential application of technology to education for the handicapped was carried out during the quarter.

14. KEY WORDS

educational technology holography	Lincoln Training System (LTS)	teaching machines